LESSON 9

TOPIC 2

Construction Monitoring and Quality Assurance - Foundations

CONSTRUCTION MONITORING AND QUALITY ASSURANCE

Lesson 9 - Topic 2
Foundations

Slide 9-2-1

header

CONSTRUCTION MONITORING AND QUALITY ASSURANCE
Foundations

1. *Apply Dynamic Analysis to Pile Design*
2. *Evaluate Pile Equipment Acceptability*

ACTIVITY: *Wave Equation Applications*

Slide 9-2-2

Objectives

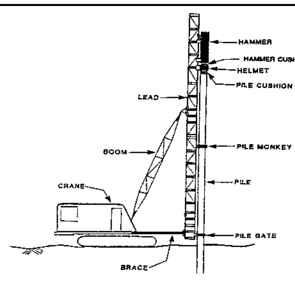
Slide 9-2-3

Comic slide to illustrate crude process of pile driving.

Both the Pile and the Driving Equipment Must Be Sized to Permit Pile Installation to the Designed Length Without Damage

Slide 9-2-4

Introduce concept of matching pile size, equipment size and soil resistance.



Pile Support System

Slide 9-2-5

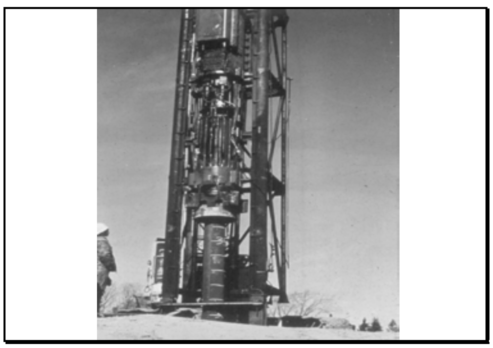
Explain the main elements of the support system that need to be controlled in the specifications and the field. In this session the instructor should thoroughly explain the equipment although some students may already have this basic knowledge. Focus on the leads as a key item that controls the alignment of the hammer-helmet-pile components to insure that each blow of the hammer is concentric to the pile.

Slide 9-2-6

Case histories showing various systems with various degrees of control. This example is a set of “hanging” leads that are not being properly employed as judged by the varying inclinations of the piles that have just been driven. Inspectors need training on such pile equipment to appreciate which equipment is prone to which problems.

Slide 9-2-7

Case histories showing various systems with various degrees of control. In this example a fixed set of leads is holding the pile and the driving system in proper alignment. Point out the alignment of all elements to the group. Also note that the hammer type is an open end diesel hammer.

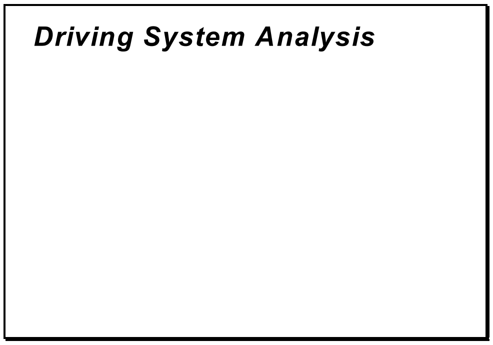


Slide 9-2-8

Case histories showing various systems with various degrees of control. Note the complexity of some of the hammer types that are in used. This is a closed end diesel hammer.

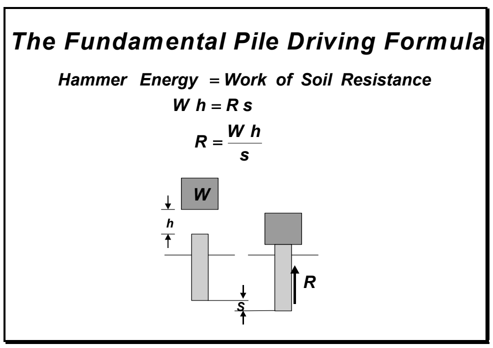
Slide 9-2-9

Case histories showing various systems with various degrees of control. This is vibratory hammer. These hammer are preferred in certain soil types by contractors as the rate of pile penetration can be very fast. However the inspector has no reliable method to determine the capacity of the pile with depth during the installation. Specifications need to include provisions for determining the pile capacity of vibratory driven piles and determining if damage has occurred to the pile.



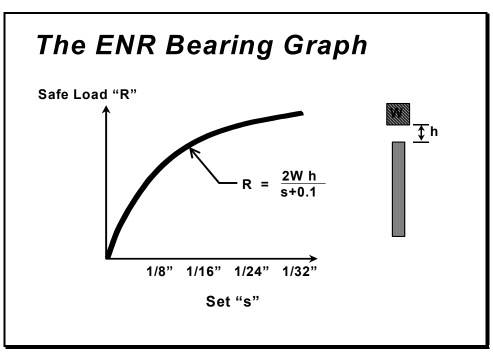
Slide 9-2-10

Introduce driving system analysis. Ask the group why the elements of the driving system are important to control and list answers on a flip chart (answer is that the driving system must be large enough to advance the pile to the desired design depth/capacity and the hammer must not damage the pile).



Slide 9-2-11

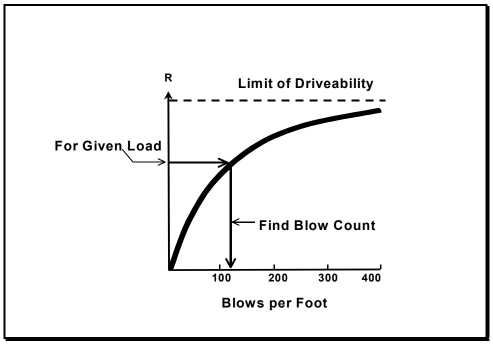
History of dynamic formula for pile control. Relate that this formula was developed in the late 1800's. The concept is that the hammer energy advances the pile a distance s against a resistance R during each hammer blow. If that is correct, then soil resistance can be found if the weight of the ram and the height of drop are known and the set per blow measured. However this formula assumes a Newtonian impact. Anyone who has seen a pile driving operation will quickly realize this is not a Newtonian operation.



Slide 9-2-12

History of dynamic formula for pile control. The ENR formula was developed based on the fundamental concepts and data from numerous pile projects. Note that the term R is the safe pile load as opposed the ultimate pile load in the fundamental formula. The ENR formula gained quick acceptance due to the simplicity of the formula as only the set per blow, s, needed to be measured to find the safe load. ENR remains popular today although subsequent studies showed the hidden safety factor to vary wildly depending on driving equipment and ground conditions.

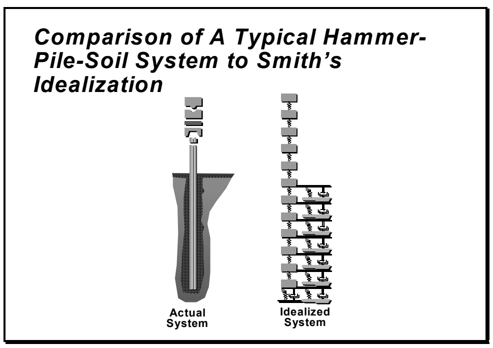
Ask the group what common method of measurement is used instead of set to monitor pile driving (answer is blows per foot which is the reciprocal of the set).



Slide 9-2-13

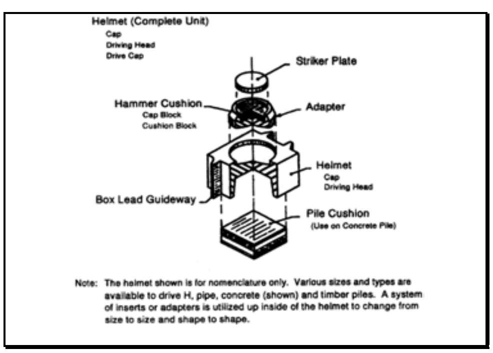
History of dynamic formula for pile control. After the group answers the last question, show this slide as the common method that was used in the past to find the required blow count for an allowable pile design load. However the important point to be made here is that some limit exists as to how deep a pile can be driven in any situation.

Ask the group what are the three elements that control how deep the pile can be driven, (answer is the properties of the hammer, the pile, and the soil).



Slide 9-2-14

Evolution to wave equation improves prediction of capacity. Engineers have realized for many years that pile driving was not a Newtonian problem, but a problem in wave mechanics. The pile wave equation was developed to accounts for the variations in the equipment used for driving, to assess the energy losses in delivering useful energy to the pile, and to account for the losses in energy due to damping effect of the soil. Although not perfect, the wave equation is the best tool the engineer have available to predict pile capacity from hammer blow count.



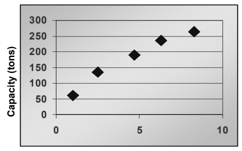
Slide 9-2-15

Explain how important the elements in the drive cap are in relation to the required blow count for pile capacity.

Pile Driving Analysis – Wave Equation Output

14" Square Prestressed Concrete Pile

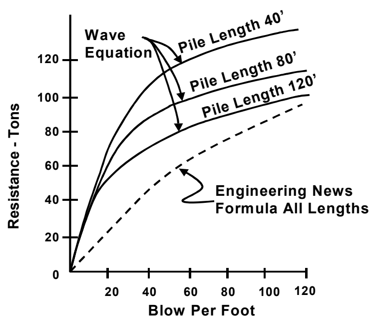
6" Micarta Cap Block, 6" Hardwood Pile Cushion



Blows Per Inch	Capacity (tons)	Max Comp Stress (PSI)	Max Tensile Stress (PSI)
1.0158	61	3738	2394
2.5309	136	3874	1661
4.6649	190	3984	1367
6.3113	236	4036	1208
8.2801	264	4076	1086

Slide 9-2-16

Explain how to read a wave equation output. Note the student exercises to follow will require wave equation output interpretation.



Slide 9-2-17

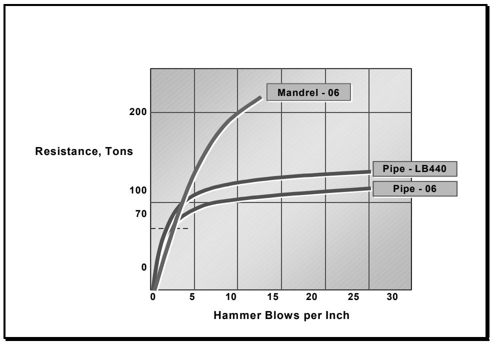
Explain the effect of pile length (stiffness) on blow count.

Pile Driving Analysis – Pile Mandrels for Shell Piles

- ***Removable pneumatic device for thin wall pile installation***
- ***High stiffness greatly improves driveability***
- ***Requires "doodle hole" for insertion into pile***

Slide 9-2-18

Introduce the concept of improving the stiffness by using a mandrel. Ask who knows what a doodle hole is?



Slide 9-2-19

Show case history of mandrel use. The 70-ton design load pipe piles on this project were to be driven according to an ENR blow count of about 15 blows per inch. The contractor asked to use a mandrel to drive the piles. The project staff agreed as long as the ENR blow count was achieved. The contractor proceeded to drive the piles to three times the estimated length to achieve blow count. Driving was eventually stopped and a load test determined that the piles had in excess of twice the desired capacity. A revised blow count was then determined by wave equation to prevent unnecessary pile overruns.

Slide 9-2-20

Show a second case history of mandrel use. Note that the pile wall thickness needs to be adequate to resist excess pore pressures created by the pile driving. These shells were too thin the resist the pressures and collapsed as soon as the mandrel was removed.

Allowable Stress Levels in Piles

Pile Type	*Allowable Driving Stress*
Steel	*0.9 Fy*
Concrete	*(0.85 F'c – Effective Prestress) In Compression*
	(3 √F'c + Effective Prestress) In Tension
Timber	*3 F'a (Not to Exceed 3000 psi)*
Where:	*Fy = Yield Strength of Steel* *F'c = 28 day Concrete Cylinder Strength* *F'a = Allowable Comrpessive Stress of Timber Including Allowance for Treatement Effects*

Slide 9-2-21

Introduce allowable stress levels for driving pile and clearly differentiate from static stress levels. Note the student exercises to follow will require the use of stress limits.

Slide 9-2-22

Show a few case histories of pile damage. The worst problem is when damage occurs after the pile is below ground. If the damage is detected the pile is usually pulled and a new pile driven. If the damage is not detected the problem may not become evident until structural loads are applied to the pile. The bottom line is that highway agencies need to consider pile overstress caused by the driving operation.

Slide 9-2-23

Show a few case histories of pile damage. The worst problem is when damage occurs after the pile is below ground. If the damage is detected the pile is usually pulled and a new pile driven. If the damage is not detected the problem may not become evident until structural loads are applied to the pile. The bottom line is that highway agencies need to consider pile overstress caused by the driving operation.

Slide 9-2-24

Mention that the best tip protection are pile points. These points are produced in various shapes and sizes to provide either better penetration or increased end bearing area.

Construction Considerations in Design

Intelligent Preparation of Plan and Specifications Can Only Be Done By One Who Understands the Construction Operation As Well as Structural Design Concepts

Slide 9-2-25

Emphasize that pile driving must be considered by the designer. Ask students to list properties of the hammer, the pile and the soil, which affect driveability. Instructor writes answer on flip chart.

SOILS AND FOUNDATIONS WORKSHOP

Standard Specifications

"In the Absence of Pile Load Tests the Safe Bearing Value for Piles Shall be Determined by the Following Formulae:

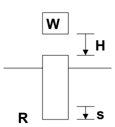
ENR Formulae or Modifications"

Slide 9-2-26

Review the common use of ENR and the associated problems with the formula.

SOILS AND FOUNDATIONS WORKSHOP

ENR Formula Factor of Safety



Fundamental Formula

$$W^{\#}H(ft) = R^{\#}s(ft)$$

$$R = \frac{WH}{s}$$

Where R = ultimate soil resistance

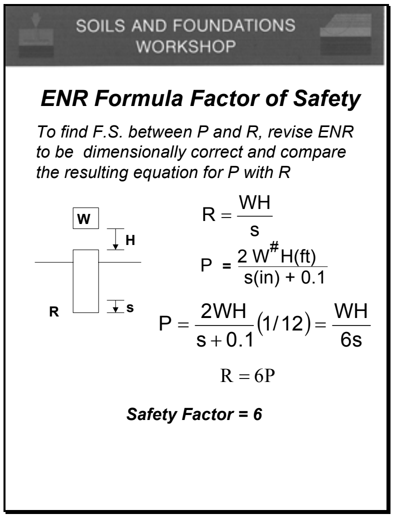
ENR Formula

$$P = \frac{2\,W^{\#}H(ft)}{s(in) + 0.1}$$

Where P = design load in #

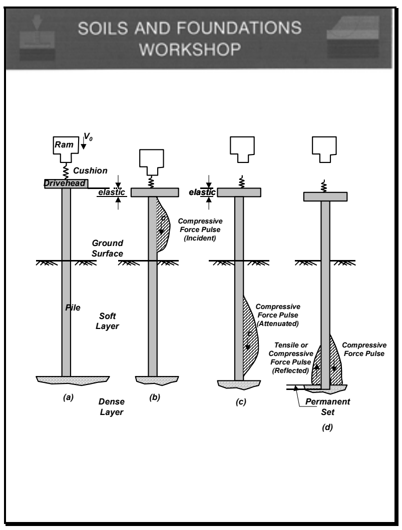
Slide 9-2-27

Instructor, ask students how properties of hammer, pile, and soil written previously on the flip chart, are accounted for by ENR formula (answer is only the hammer energy is accounted for). Then ask what is the built-in safety factor in the ENR formula (6) and derive on next overhead.



Slide 9-2-28

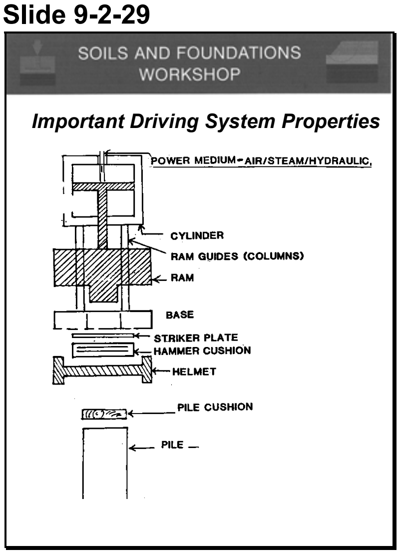
After completing the derivation, ask what is the actual range of safety factor in ENR (answer is 2/3 to 20).



Slide 9-2-29

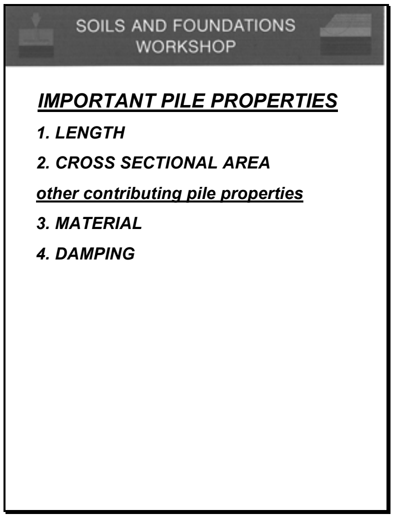
Review how a force wave is generated by the hammer and transmitted down the pile. Note the importance of the amplitude and period of the wave and the damping which occurs in the soil.

Optional: Instructor demonstrates GRLIMAGE program.



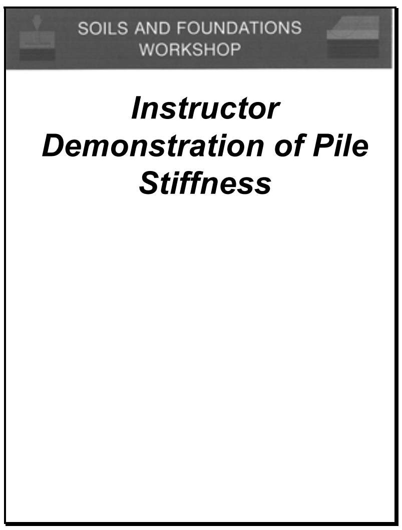
Slide 9-2-30

Instructor asks what information is available to the host agency prior to construction about the hammer that the contractor will use in construction. Note that the elements shown in this overhead will have an influence on the hammer blow count needed to assure the pile load is achieved.



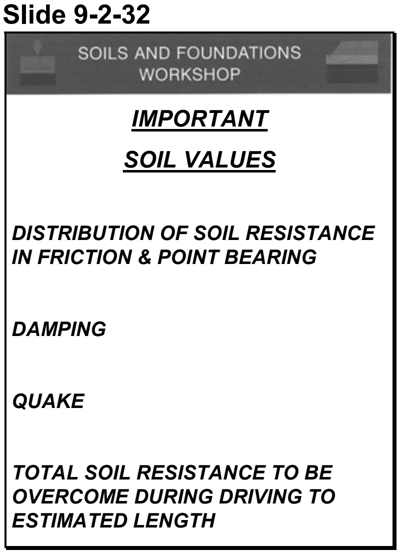
Slide 9-2-31

Review important pile properties. Mention that other properties have a minor effect on pile but are beyond the scope of this course.



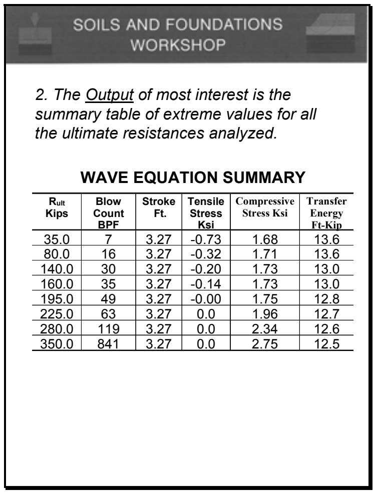
Slide 9-2-32

Instructor then does demo with slender wood dowel and thick wood dowel to show stiffness concept.



Slide 9-2-33

Review important soil properties



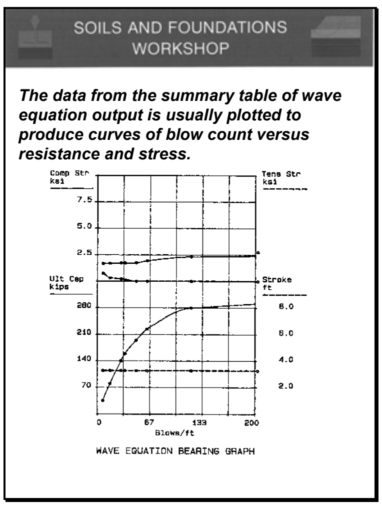
R_{ult} Kips	Blow Count BPF	Stroke Ft.	Tensile Stress Ksi	Compressive Stress Ksi	Transfer Energy Ft-Kip
35.0	7	3.27	-0.73	1.68	13.6
80.0	16	3.27	-0.32	1.71	13.6
140.0	30	3.27	-0.20	1.73	13.0
160.0	35	3.27	-0.14	1.73	13.0
195.0	49	3.27	-0.00	1.75	12.8
225.0	63	3.27	0.0	1.96	12.7
280.0	119	3.27	0.0	2.34	12.6
350.0	841	3.27	0.0	2.75	12.5

Slide 9-2-34

Instructor explains how to read the wave output from the summary table.

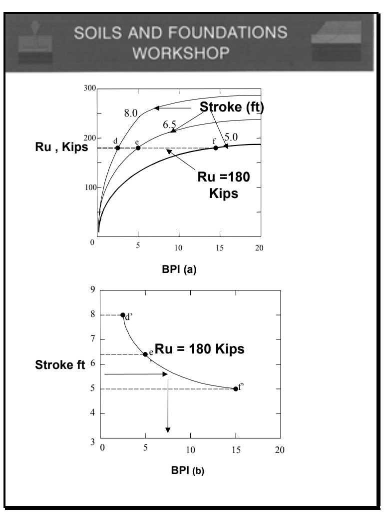
After reading compressive and tensile stresses predicted for the pile, instructor asks if these stresses are within allowable values. The answer is yes. However, point out that a significant tensile stress was noted at a very low driving resistance. If this value was higher than the allowable tensile stress, the designer should perform a supplemental wave equation analysis for a partially embedded pile.

Instructor also asks what type of hammer was used for this example.



Slide 9-2-35

Instructor explains how to read the wave output from the graph of the summary table results.



Slide 9-2-36

Instructor explains difference between diesel and air-steam hammer output.

SOILS AND FOUNDATIONS WORKSHOP

General Criteria for Acceptable Pile Driveability

1. Hammer Blows Between 30-144 per foot

2. Acceptable Driving Stress

Pile Type	Allowable Driving Stress
Steel	0.9 F′y
Concrete	(0.85 F′c – effective prestress) in compression
	(3 √F′c + effective prestress) in tension
Timber	3 F′a (not to exceed 3000 psi)

Where: Fy = Yield strength of steel
F′c = 28 day concrete cylinder strength
F′a = allowable compressive stress of timber including allowance for treatment effects

Slide 9-2-37

Explain criteria for acceptable driveability of a pile.

Ask students to open reference manual to section 9.3 and review the information that was just covered in the previous slides and overheads for lesson 9-2.

Instructor should now review material in the Reference Manual.

SOILS AND FOUNDATIONS WORKSHOP

Example: Determine If The 14” Square Concrete Pile Can Be Driven To A Driving Capacity Of 225 Kips By Using The Wave Equation Output Summary. Assume The Concrete Compressive Strength Is 4000 psi And The Pile Prestress Force Is 700 psi.

WAVE EQUATION OUTPUT SUMMARY

R_{ult} Kips	Blow Count BPF	Stroke Ft.	Tensile Stress Ksi	Compressive Stress Ksi
35.0	7	3.27	-0.73	1.68
80.0	16	3.27	-0.32	1.71
140.0	30	3.27	-0.20	1.73
160.0	35	3.27	-0.14	1.73
195.0	49	3.27	-0.00	1.75
225.0	63	3.27	0.0	1.96
280.0	119	3.27	0.0	2.34
350.0	841	3.27	0.0	2.75

Slide 9-2-38

Instructor demonstrates use of driveability information in example.

SOILS AND FOUNDATIONS WORKSHOP

Solution:

Acceptable driveability depends on achieving the hammer blows between 30 and 144 at the driving capacity, and assuming that the allowable compressive and tensile driving stress are not exceeded.

1. ***At R_{ult} = 225 Kips, blow count = 63 which is between 30 and 144. O.K.***

2. ***For concrete piles, the allowable driving stresses are:***
   - ***Compressive stress allowed = 0.85 F’c – prestress = 3400 – 700 = 2700 psi, actual Max. compressive stress up to 225 Kips from wave equation output summary is 1.96 ksi or 1960 psi $\leq$ 2700 psi allowed value. O.K.***
   - ***Tensile stress allowed = 3√F′c + prestress = 190 + 700 = 890 psi, actual Max. tensile stress up to 225 Kips from wave equation output summary is 0.730 ksi or 730 psi < 890 psi allowed value. O.K.***

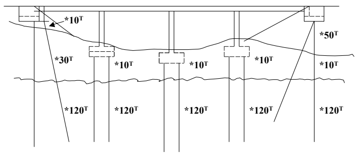
Slide 9-2-39

Instructor demonstrates use of driveability information in example. Explain that although the tensile stress at the drawing resistance of 225 tons is 0 psi, a higher tensile stress may be observed in the pile if either the driving resistance is lower than expected or when the pile is only partially embedded against low resistance. Generally good practice to check tensile force at lower driving resistances.

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 8

Design Phase Driveability Analysis



The Profile Shows the Calculated Driving Resistance in Each Soil Layer at Each Footing for the Proposed 12″ Diameter Steel Pipe Piles (Steel F_y = 36 ksi). Using the Maximum Driving Resistance at Any Footing, find the Anticipated Maximum Driving Stress and Blow Count From the Wave Equation Summaries Shown for Three Pile Sizes. Compare These Values to the Recommended Friction Pile Values for Blow Count and Driving Stress to Determine the Minimum Acceptable Pile Wall Thickness for the Pipe Piles at This Site.

Slide 9-2-40

Student pile driveability exercise, which requires use of wave equation output on next overhead. The purpose is to familiarize the students with wave equation output use in design and with the FHWA criteria for acceptable pile driveability. Instructor chooses team to present answer.

Instructor asks group if this stress check is now done in design by the agency.

Please refer to the end of the lesson for this exercise.

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 8

GRLWEAP S & F STUDENT EXERCISE 0.250″ WALL THICKNESS

R_{ult} Kips	Bl Ct bpf	Stroke (eq. Ft)	Min str. ksi	Max str. ksi	Enthru kip-ft
260.0	35.3	3.25	-0.85	36.34	14.8
360.0	111.8	3.25	-0.98	42.07	13.8

GRLWEAP S & F STUDENT EXERCISE 0.312″ WALL THICKNESS

R_{ult} Kips	Bl Ct bpf	Stroke (eq. Ft)	Min str. ksi	Max str. ksi	Enthru kip-ft
260.0	31.8	3.25	-0.68	28.58	15.1
360.0	72.9	3.25	-0.70	35.98	14.2

GRLWEAP S & F STUDENT EXERCISE 0.375″ WALL THICKNESS

R_{ult} Kips	Bl Ct bpf	Stroke (eq. Ft)	Min str. ksi	Max str. ksi	Enthru kip-ft
260.0	30.2	3.25	-0.45	24.67	15.2
360.0	58.8	3.25	-0.95	30.47	14.5

Slide 9-2-41

Please refer to the end of the lesson for this exercise.

SOILS AND FOUNDATIONS WORKSHOP

SOLUTION TO EXERCISE NO. 8

		OK	N.G.
Pile 1: 0.250″ wall thickness (9.77 in^2)			
Maximum Stress	42	☐	☒
Blow Count	112	☒	☐
Pile 2: 0.312″ wall thickness (12.19 in^2)			
Maximum Stress	36	☐	☒
Blow Count	73	☒	☐
Pile 3: 0.375″ wall thickness (14.60 in^2)			
Maximum Stress	30.4	☒	☐
Blow Count	59	☒	☐

Select Pile 3, 0.375″ Wall Thickness, Which meets both the Blow Count and Stress Criteria.

Slide 9-2-42

Solution to exercise 8.

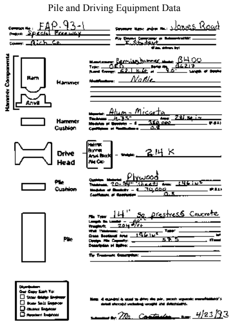
Please refer to the end of the Participant Workbook for the solution to this exercise.

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 9
Hammer Approval

The contractor has submitted the pile equipment data form and the wave equation analysis for a 14 ″square prestressed concrete pile (f′c = 5,000 psi and 700 psi prestress) with a design capacity of 115 kips and a driv ing resistance of 300 kips. Should you accept or reject this hammer?

Pile and Driving Equipment Data



Slide 9-2-43

Student hammer approval exercise using the results of wave equation output and the Pile/Driving Equipment Form. Purpose is to familiarize student with the use of the wave equation in construction control and with the typical information submitted by a pile contractor, and to reinforce the FHWA driveability criteria. Instructor chooses team to present answer.

Instructor asks if hammer has reserve capacity to drive pile further than planned without damage.

Please refer to the end of the Participant Workbook for the solution to this exercise.

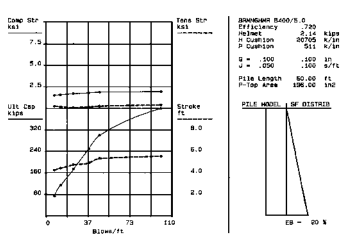
SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 9 (CONT'D)

Federal Highway 01/28/93 GRLWEAP S&F STUDENT EXERCISE HAMMER APPROVAL

Rut kips	Bl Ct bpf	Stroke (ft) down	up	min Str ksi	i,t	max Str ksi	i,t	ENTHRU kip-ft	Bl Rt b/min
75.0	7.2	4.3	4.3	-.30	(7, 19)	1.54	(2, 12)	13.2	56.7
115.0	12.5	4.5	4.5	-.20	(9, 21)	1.62	(2, 12)	11.7	55.3
175.0	24.0	4.8	4.7	-.11	(10, 21)	1.73	(2, 12)	10.1	53.8
250.0	37.3	5.0	5.1	-.19	(9, 30)	1.82	(2, 12)	8.8	52.4
300.0	47.0	5.4	5.3	-.28	(8, 29)	1.90	(2, 12)	8.8	50.9
400.0	102.2	5.6	5.7	-.41	(5, 28)	1.96	(2, 12)	8.1	49.5

G R L W E A P - Federal Highway Admin.
S&F STUDENT EXERCISE HAMMER APPROVAL 01/29/93



Slide 9-2-44

Student exercise wave equation information.

Please refer to the end of the Participant Workbook for the solution to this exercise.

SOILS AND FOUNDATIONS WORKSHOP

SOLUTION TO EXERCISE NO. 9

Acceptable Driving Stresses:
Maximum Compressive Stress = (0.85 × 5,000 psi) – 700 psi = **3,550 psi**
Maximum Tensile Stress = (3 × √5,000 psi) + 700 psi = **912 psi**

Acceptable Blow Count Range: **30-144** blows/foot

Wave Equation Results: 300 Kips Driving Resistance

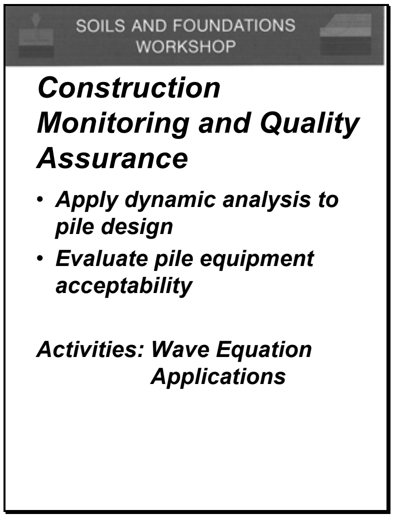
Max (compressive) stress = 1.9 ksi = 1,900 psi < 3,550 psi okay
Min (tensile) stress = -0.28 ksi = -280 psi < -912 psi okay
Blow Count = 47 bpf between 30 & 144 bpf okay

HAMMER APPROVED ✓

Slide 9-2-45

Solution to exercise 9.

Please refer to the end of the Participant Workbook for the solution to this exercise.



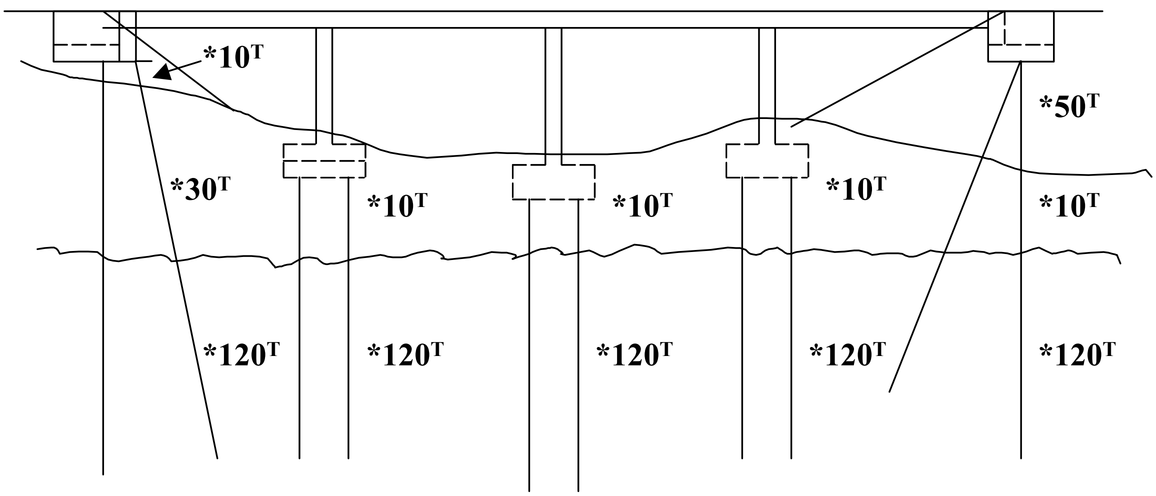
Slide 9-2-46

Repeat objectives for lesson 9 topic 2.

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 8

Design Phase Driveability Analysis



The Profile Shows the Calculated Driving Resistance in Each Soil Layer at Each Footing for the Proposed 12″ Diameter Steel Pipe Piles (Steel F_y = 36 ksi). Using the Maximum Driving Resistance at Any Footing, find the Anticipated Maximum Driving Stress and Blow Count From the Wave Equation Summaries Shown for Three Pile Sizes. Compare These Values to the Recommended Friction Pile Values for Blow Count and Driving Stress to Determine the Minimum Acceptable Pile Wall Thickness for the Pipe Piles at This Site.

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 8

GRLWEAP S & F STUDENT EXERCISE 0.250″ WALL THICKNESS

R_{ult} Kips	Bl Ct bpf	Stroke (eq. Ft)	Min str. ksi	Max str. ksi	Enthru kip-ft
260.0	35.3	3.25	-0.85	36.34	14.8
360.0	111.8	3.25	-0.98	42.07	13.8

GRLWEAP S & F STUDENT EXERCISE 0.312″ WALL THICKNESS

R_{ult} Kips	Bl Ct bpf	Stroke (eq. Ft)	Min str. ksi	Max str. ksi	Enthru kip-ft
260.0	31.8	3.25	-0.68	28.58	15.1
360.0	72.9	3.25	-0.70	35.98	14.2

GRLWEAP S & F STUDENT EXERCISE 0.375″ WALL THICKNESS

R_{ult} Kips	Bl Ct bpf	Stroke (eq. Ft)	Min str. ksi	Max str. ksi	Enthru kip-ft
260.0	30.2	3.25	-0.45	24.67	15.2
360.0	58.8	3.25	-0.95	30.47	14.5

SOILS AND FOUNDATIONS WORKSHOP

SOLUTION TO EXERCISE NO. 8

		OK	N.G.
Pile 1: 0.250″ wall thickness (9.77 in^2)			
Maximum Stress	42	☐	☒
Blow Count	112	☒	☐
Pile 2: 0.312″ wall thickness (12.19 in^2)			
Maximum Stress	36	☐	☒
Blow Count	73	☒	☐
Pile 3: 0.375″ wall thickness (14.60 in^2)			
Maximum Stress	30.4	☒	☐
Blow Count	59	☒	☐

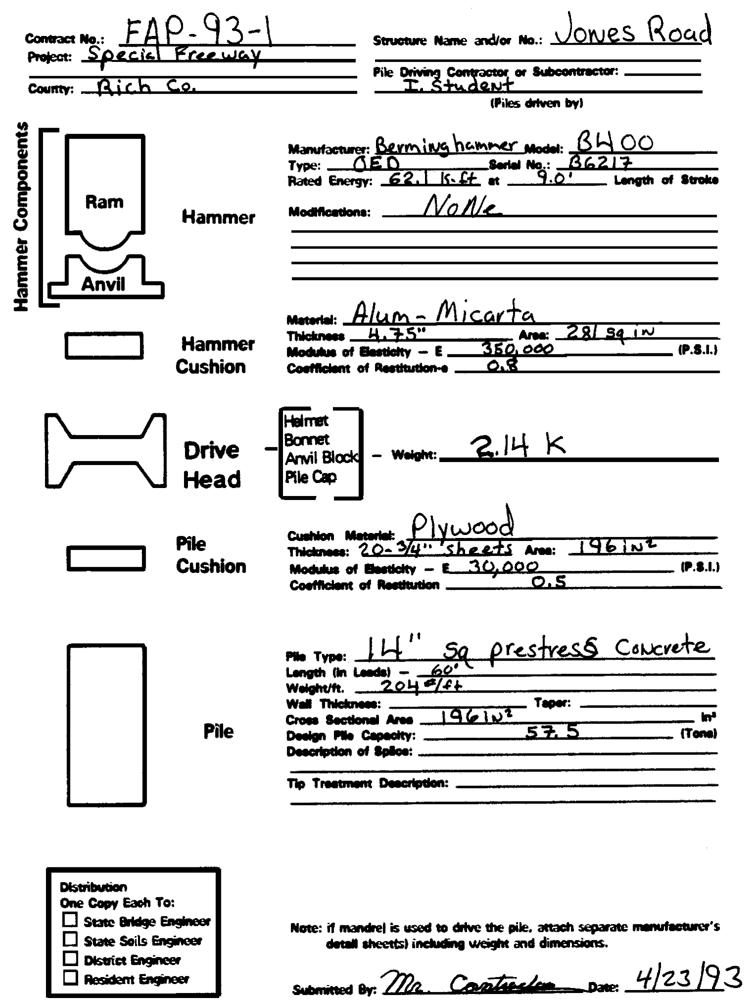
Select Pile 3, 0.375″ Wall Thickness, Which meets both the Blow Count and Stress Criteria.

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE NO. 9
Hammer Approval

The contractor has submitted the pile equipment data form and the wave equation analysis for a 14 ″square prestressed concrete pile (f′c = 5,000 psi and 700 psi prestress) with a design capacity of 115 kips and a driv ing resistance of 300 kips. Should you accept or reject this hammer?

Pile and Driving Equipment Data



Contract No.: FAP-93-1
Project: Special Freeway
County: Rich Co.
Structure Name and/or No.: Jones Road
Pile Driving Contractor or Subcontractor: I. Student
(Piles driven by)

Hammer Components: Ram, Anvil

Hammer
Manufacturer: Berminghammer Model: B400
Type: OED Serial No.: B6217
Rated Energy: 62.1 k-ft at 9.0' Length of Stroke
Modifications: NoNe

Hammer Cushion
Material: Alum - Micarta
Thickness 4.75" Area: 281 sq in
Modulus of Elasticity – E 350,000 (P.S.I.)
Coefficient of Restitution-e 0.8

Drive Head – Helmet / Bonnet / Anvil Block / Pile Cap – Weight: 2.14 K

Pile Cushion
Cushion Material: Plywood
Thickness: 20-3/4" sheets Area: 196 in²
Modulus of Elasticity – E 30,000 (P.S.I.)
Coefficient of Restitution 0.5

Pile
Pile Type: 14" sq prestress Concrete
Length (In Leads) – 60'
Weight/ft. 204 #/ft
Wall Thickness: Taper:
Cross Sectional Area 196 in² in²
Design Pile Capacity: 57.5 (Tons)
Description of Splice:
Tip Treatment Description:

Distribution
One Copy Each To:
☐ State Bridge Engineer
☐ State Soils Engineer
☐ District Engineer
☐ Resident Engineer

Note: If mandrel is used to drive the pile, attach separate manufacturer's detail sheet(s) including weight and dimensions.

Submitted By: Mr. Contractor Date: 4/23/93

SOILS AND FOUNDATIONS WORKSHOP

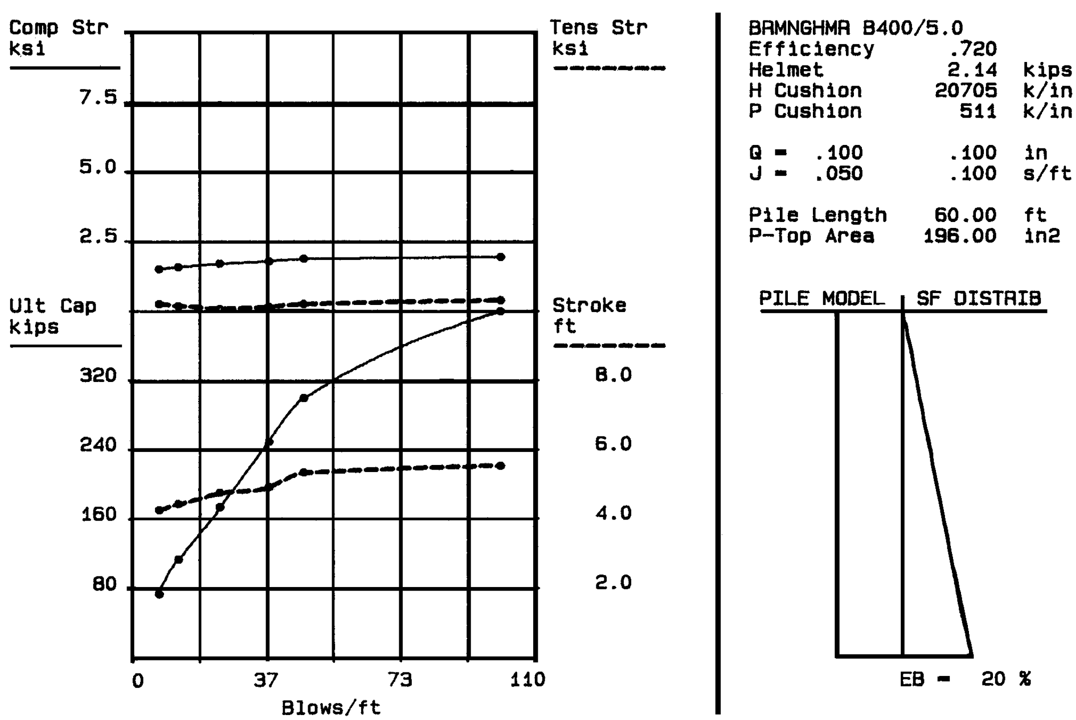
STUDENT EXERCISE NO. 9 (CONT'D)

Federal Highway 01/28/93 GRLWEAP S&F STUDENT EXERCISE HAMMER APPROVAL

Rut kips	Bl Ct bpf	Stroke (ft) down	up	min Str ksi	i,t	max Str ksi	i,t	ENTHRU kip-ft	Bl Rt b/min
75.0	7.2	4.3	4.3	-.30(	7, 19)	1.54(	2, 12)	13.2	56.7
115.0	12.5	4.5	4.5	-.20(	9, 21)	1.62(	2, 12)	11.7	55.3
175.0	24.0	4.8	4.7	-.11(	10, 21)	1.73(	2, 12)	10.1	53.8
250.0	37.3	5.0	5.1	-.19(	9, 30)	1.82(	2, 12)	8.8	52.4
300.0	47.0	5.4	5.3	-.28(	8, 29)	1.90(	2, 12)	8.8	50.9
400.0	102.2	5.6	5.7	-.41(	5, 28)	1.96(	2, 12)	8.1	49.5

G R L W E A P - Federal Highway Admin.

S&F STUDENT EXERCISE HAMMER APPROVAL 01/29/93



SOILS AND FOUNDATIONS
WORKSHOP

SOLUTION TO EXERCISE NO. 9

Acceptable Driving Stresses:
Maximum Compressive Stress = (0.85 × 5,000 psi) – 700 psi = **3,550 psi**
Maximum Tensile Stress = (3 × √5,000 psi) + 700 psi = **912 psi**

Acceptable Blow Count Range: **30-144** blows/foot

Wave Equation Results: 300 Kips Driving Resistance

Max (compressive) stress = 1.9 ksi = 1,900 psi < 3,550 psi okay
Min (tensile) stress = -0.28 ksi = -280 psi < -912 psi okay
Blow Count = 47 bpf between 30 & 144 bpf okay

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